

A MULTI-CHANNEL MICRO VALVE FOR MICRO PNEUMATIC ARTIFICIAL MUSCLE

Yong Kwun LEE and *Isao SHIMOYAMA

SAMSUNG Electronics Co.,LTD, Maetan-Dong, Paldal-Ku, Suwon, KOREA

*The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, JAPAN

Phone: (8231)-200-2438, Fax: (8231)-200-2434, E-mail: yklee@samsung.co.kr

ABSTRACT

A miniaturized Mckibben artificial muscle pneumatic actuator of 1 mm in diameter and a micromachined high-power multi-channel micro valve have been developed. The pneumatic actuator can make a contraction of 21% of its length and generate contraction force of 3.8 N when it is pressurized at 0.6 MPa. The micro valve of 19 mm x 25 mm x 2 mm has six channels. Its maximum allowable pressure and flow rate are 0.6 MPa and 830 cc/min, respectively. The actuators and the valve are integrated and applied to a skeletal hand.

INTRODUCTION

Nowadays it is increasingly important for robots to serve and help people, especially for the needs of the old and the handicapped. Entire soft body is one of the essentials for robots that interact with a human.

In this research, we have developed a soft actuator for artificial limbs including small moving parts like fingers.

We have used a pneumatic actuator called "Mckibben artificial muscle" as shown in Figure 1. It is lightweight, large-force and has high durability. Its material and motion pattern are soft and smooth [1].

However, the conventional Mckibben artificial muscle is too large to be applied to the artificial limbs including small moving parts like fingers and toes. Thus, we have tried to reduce the size of it.

In addition, a microsized large-force flow-control element is needed to develop micro pneumatic systems to be embedded in soft moving systems such as an artificial hand.

In this research, we have designed and fabricated the microsized valve with multiple channels as a control device for the micro muscle of small cross-sectional area.

A MICRO PNEUMATIC MUSCLE

A physical model of the micro artificial muscle

A Mckibben artificial muscle is modeled as shown in equations (1), (2) and (3).

Miniaturization of pneumatic actuator decreases its contraction force and contraction rate. More precisely, its contraction force is in proportional to the square of its

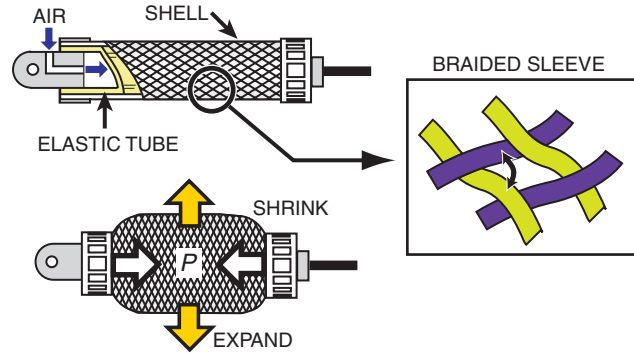


Figure 1. Structure of Mckibben pneumatic muscle

radius as shown in the equation (1), and its contraction rate is in proportional to its radius as shown in the equation (2).

Equations:

$$F = \pi a^2 p \left\{ \frac{1 - 2\nu - (2 - \nu)Q}{1 + \nu Q} \right\} \quad (1)$$

$$\frac{\Delta L}{L_0} = \frac{a^2 p}{Et} \left\{ \frac{2(1 - \nu^2)Q}{(2a + t)(\nu Q + 1)} \right\} \cong \frac{apQ}{Et} \quad (2)$$

$$Q = \frac{\Delta L}{\Delta D} / \frac{L_0}{D_0} = - \left(\frac{L_{\max} - L_{\min}}{D_{\max} - D_{\min}} \right) / \frac{L_0}{D_0} \quad (3)$$

F : Contraction force generated by a pressurized artificial muscle

E : Young's Modulus of the elastic tube

ν : Poisson's Ratio of the elastic tube

L : Length of the pneumatic artificial muscle

ΔL : Amount of contraction of the artificial muscle

L_0 : Initial length of braided sleeve shell

Q : Sleeve Factor

We tried to reduce the size of the pneumatic actuator by analyzing the physical model and modifying the parameters of the set of equations such as the sleeve factor, Q , the thickness of elastic tube, $(b - a)$. By choosing a thin tube and a sleeve carefully, we succeeded in reducing

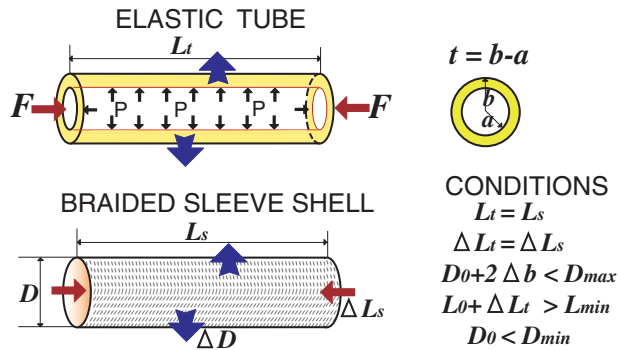


Figure 2. A physical model of the micro artificial muscle

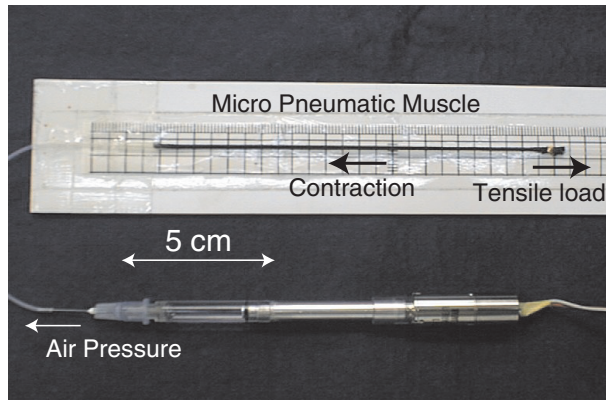


Figure 3. The Micro pneumatic artificial muscle

its diameter to 1 mm. A pneumatic artificial muscle we assembled is shown in Figure 3.

The micro artificial muscle shown in Figure 3 has advantageous features as follows:

- Softness in material and motion
- Simple and lightweight structure
- Little flux (10 μ L / cm) is needed
- Suitable for embedded pneumatic systems
- Low production cost and high power efficiency

Characteristic of Micro artificial muscle

The force and the transformation generated by a McKibben artificial muscle depend on the weave characteristics of the braided sleeve, the material properties of the elastic tube, the actuation pressure, and the muscle's length. A McKibben artificial muscle, if constructed from the materials as above, can generate a maximum contraction force of 3.8 N and a transformation of 21% in length (contraction) when it is pressurized to 0.6 MPa. It can be calculated by the equations in Figure 2 and be proven by experimental measurement [2,3].

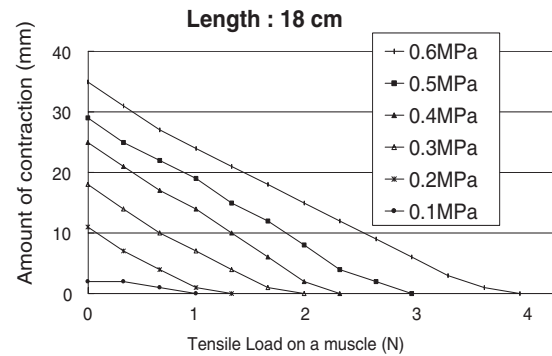


Figure 4. The amount of contraction of a pressurized small sized artificial muscle

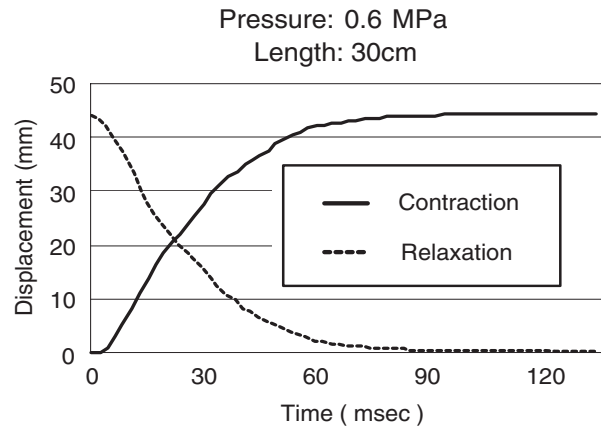


Figure 5. The transformation speed of a Micro muscle

The amount of contraction of a micro artificial muscle loaded is presented in Figure 4.

The transformation speed of a micro artificial muscle is presented in Figure 5.

MICRO PNEUMATIC SYSTEM

The pneumatic system used to be applied to large systems because devices for pneumatic systems were also large. The micro pneumatic systems have potential of moving microsystems as well as controlling a conventional machine with multi-degrees of freedom.

We developed a micro-sized airflow control valve to miniaturized pneumatic actuators and applied them to an artificial hand with skeletal framework in order to verify the performance. The architecture of a micro pneumatic system for the artificial hand is shown in Figure 6.

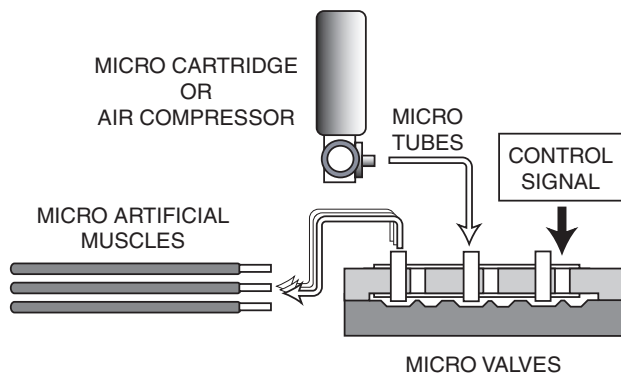


Figure 6. A micro pneumatic system

A MICRO MULTI-CH. VALVE

In order to control the micro muscle, it is necessary to switch the airflow into the muscle.

In this research, we designed and fabricated the micro valve with six channels as a control device for the micro muscle. The micro valve consists of fluidic flow channels and actuators for switching the airflow.

Flow channels were patterned using anisotropic etching on a silicon wafer of 1 mm in thickness. Figure 7(a) shows the patterned silicon wafer.

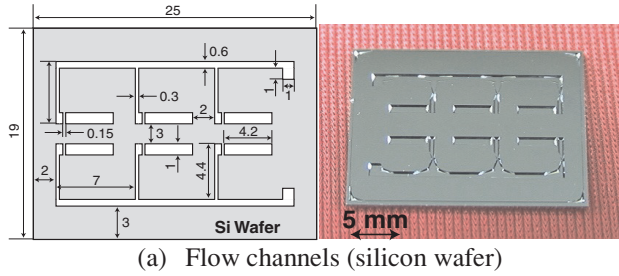
Two inlets, six outlets and six control ports were placed on Pyrex glass. Apertures on Pyrex glass were made using a diamond high-speed drill. Needle fittings were fixed on the apertures in order to connect thin silicone tubes to it. The silicon wafer and the glass were bonded using anodic bonding as shown in Figure 7 (b). The bonded structure has a top surface area of 19 mm x 25 mm, and a thickness of 2 mm.

As actuators for switching airflow, a patterned sheet of surface memory alloy (SMA) were mounted on the control ports. The SMA sheet was patterned using a YAG (yttrium-aluminum-garnet) laser. Figure 7(c) shows the fabricated SMA film actuator.

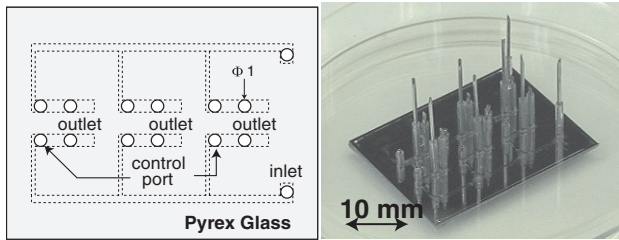
Figure 8 shows the structure of the fabricated micro valve with six channels for pneumatic micro muscles. It could control the pressure of 0.6 MPa and the flow rate of 830 cc/min.

Figure 9 shows the control ability of the valve for the micro muscle. The response time of the micro valve in switching from the opened state to the closed state was 450 ms, where an operating voltage was 9 V; the pressure from inlet was 0.6 MPa.

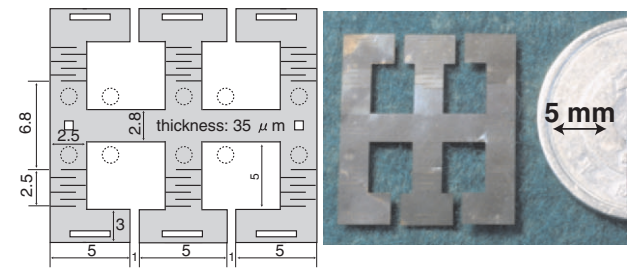
Figure 10 shows the switching speed of the valve vs. operating voltage.



(a) Flow channels (silicon wafer)



(b) Inlets and control ports (Pyrex glass)



(c) Actuator of control ports (SMA)

Figure 7. Each part of the micro valve

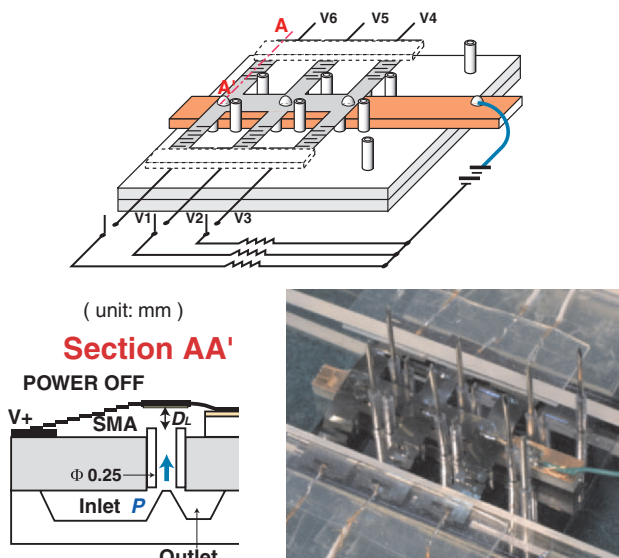


Figure 8. Structure of the micro valve

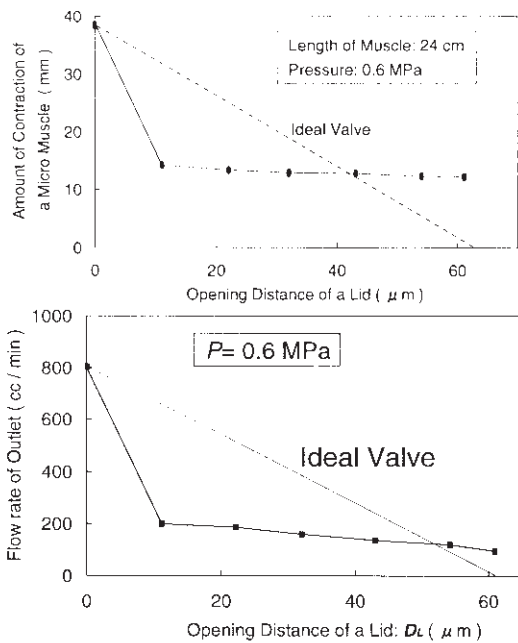


Figure 9. Control of the muscle by the micro valve

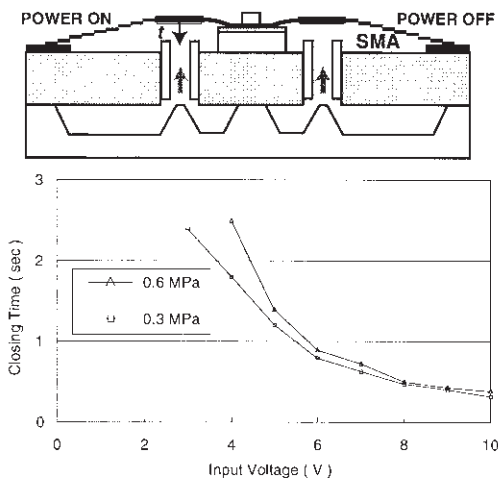


Figure 10. Response time in switching the micro valve

AN ARTIFICIAL HAND

As an example of applications of a micro pneumatic system that consists of micro pneumatic muscles and a micro valve, we tried to build an artificial hand that is similar to a real human hand in motion.

We used a skeleton model of human hand as a frame of the artificial hand in order to make the artificial hand

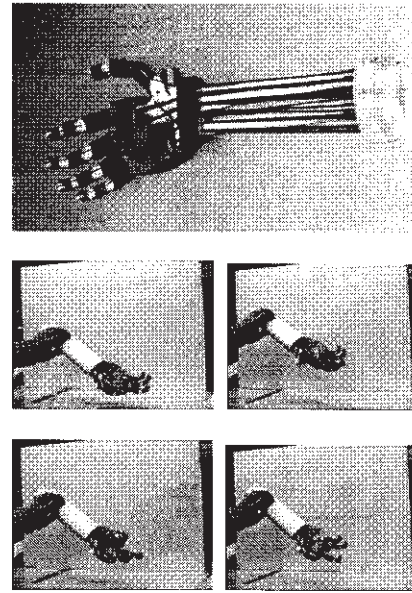


Figure 11. An artificial hand actuated by the micro muscles

similar to real human hand in structure as well as in motion. Figure 11 shows the artificial hand.

CONCLUSIONS

We have built the micro pneumatic system to drive a soft artificial hand. We developed a micro muscle with a diameter of 1 mm as a soft pneumatic actuator.

In order to control the muscles, we designed and fabricated the micro valve with six channels as a compact control device. The micro valve has six channels in a size of 19 mm x 25 mm x 2 mm. It could control the high pressure of 0.6 MPa and the flow rate of 830 cc/min. It could control each port from open to close with a time of 450 ms when the SMA film actuator was operated at 9 V.

REFERENCES

- [1] C. P. Chou, B. Hannaford, "Static and Dynamic Characteristics of McKibben Pneumatic Artificial Muscles", 1994 IEEE International Conference on Robotics and Automation, 1994.
- [2] Y. K. Lee, I. Shimoyama, "A skeletal framework artificial hand actuated by pneumatic artificial muscles", 1999 IEEE International Conference on Robotics and Automation, pp.926-931, 1999.
- [3] Y. K. Lee, I. Shimoyama, "A micro rubber artificial muscle driven by a micro compressor for artificial limbs", International Conference on New Actuators, B3.2, pp.272-275, 2000.